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Clean Energy Council Industry Report
Improving Off-Grid Renewable Energy Opportunities

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Prepared by Hydro Electric Corporation ABN48 072 377 158
t/a Entura 89 Cambridge Park Drive Cambridge Tasmania 7170 Australia

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	(name)	(signature)	(date)
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Executive summary

The Clean Energy Council (CEC) engaged Entura to prepare a report discussing off-grid renewable energy opportunities in Australia. This paper discusses the following aspects of renewable energy in off-grid scenarios:

- Review and description of the available technology for renewable energy off-grid power generation;
- High level mapping of the available renewable energy resource overlaid with potential off-grid customers;
- Estimates of diesel based generation unit costs, grid connection costs and renewable energy generation unit costs;
- Discussion of project evaluation for off-grid renewable energy projects, inputs required to undertake an evaluation and discussion of potential contract models for implementation;
- Discussion of the integration of renewable energy into hybrid systems, including energy storage and enabling technologies;
- Details of three case studies of off-grid projects using renewable energy within Australia; and
- Identification of potential action that the Federal Government could implement to assist or improve the uptake of off-grid renewable energy.

Renewable energy as a source of power for off-grid projects is ready for implementation now. There are already numerous projects within Australia where renewable energy has been integrated into off-grid power supplies successfully.

Presently, many off-grid power supplies are dependent on diesel based generation. Thus the price of diesel fuel is an important driver for the uptake of renewable energy. When the price of diesel fuel peaked at around $1.80 per litre during 2008, there was an increased interest in the uptake of renewable energy for off-grid power supply. However, the suppression of diesel prices following the global financial crisis has temporarily reduced this urgency. Predictions that diesel fuel prices are currently at the low end of the scale and will only get higher suggest that it is only a matter of time before renewable energy is the preferred source of power supply as their costs plateau or decrease while the cost of diesel increases.

Presently solar power or wind power are the chosen forms of power supply based on their ability to be installed virtually anywhere. In particular, based on the available resources, solar power appears to be the preferred choice for northern parts of Australia and wind power is the preferred choice for southern parts of Australia. However, the preferred power source should be based on an assessment of the best outcome of the project based on the project's drivers.

Other mature renewable energy grid connected power supply options of hydro power and geothermal power have been rarely used in off-grid scenarios in Australia due to the absence of site specific conditions that they require. Thus it is unlikely that they will be suitable for future projects, although they should not be precluded from preliminary assessments. Other forms of renewable energy supply (such as wave or tidal power) are still in their infancy and are also site dependent and thus unlikely to be suitable in the near future.

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1. Introduction

The Clean Energy Council (CEC) has engaged Entura, part of the Hydro Tasmania group[1], to prepare a report discussing off-grid renewable energy opportunities in Australia.

Specifically the CEC requested that the report discuss the following topics:

- Review and description of the available technology for renewable energy off-grid power generation;
- High level mapping of the available renewable energy resource overlaid with potential off-grid customers;
- Evaluation of diesel based generation unit energy costs, grid connection costs and off-grid renewable energy generation unit costs;
- Discussion of project evaluation methods for off-grid renewable energy projects;
- Discussion of the integration of renewable energy into hybrid systems;
- Details of three case studies within Australia; and
- Identification of potential actions that the Federal Government could implement to assist or improve the uptake of off-grid renewable energy.

In the context of this report, off-grid projects are defined as those projects requiring a power supply above a nominal capacity of 10 kW that are not connected to the National Electricity Market, the South-West Interconnection System or the North-West Interconnected System.

It is to be noted that the discussion presented in this report is general for all potential off-grid projects and not specific to any one project. A feasibility assessment should be undertaken for each individual off-grid project, which should include a proper assessment of the available renewable energy resource.

[1] Entura is a division of Hydro Tasmania. Entura was known as Hydro Tasmania Consulting up until 3 September 2010. Hydro Tasmania and Entura are brand names of the Hydro-Electric Corporation.

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2. Renewable Energy Generation Technologies

This section discusses the available renewable energy technologies that are widely adopted for use in both off-grid stand-alone power systems and isolated grid applications. These technologies include:

- solar power
- wind power
- hydro power
- geothermal power

Emerging renewable energy technologies such as wave or tidal power are not yet widely available, are restricted to very site specific locations and at the time of this report not considered to be mature technologies suitable for commercial full scale deployment. Enabling technologies (such as energy storage) and integration technology are discussed in Section 6.

2.1 Solar Power

Solar power has been widely used for off-grid projects in Australia for numerous years, with many remote communications and data collection stations having made use of solar power for many years. One of the first sizeable solar off-grid projects was installed in 2002 for the Bulman communities in the Northern Territory using solar PV.

Most off-grid projects involving solar power have been in the northern part of Australia through Western Australia, South Australia, the Northern Territory and Queensland where the overall resource is superior to wind power.

It should be noted that similar solar technologies are also available and emerging for water desalination, building and process heating and cooling, water pre-heating or boosting within off-grid hybrid systems, which are not described in this report.

2.1.1 Off-Grid Solar Power Market Sectors

The solar off-grid market sectors are shown in Table 2-1, with an indicative unit size ranges for the solar power plant installed in each sector.

Table 2-1: Off-Grid Solar Market Sectors

Off-Grid Sector	Indicative Unit Size Range for Solar Power Generation Plant Installed			
	to 10 kW	10 to 50 kW	50 kW to 1 MW	1 MW to > 10's MW
Households				
Pastoral Stations				
Communities				
Tourist Facilities				
Small Industrial*				
Pumping & Irrigation				
Mine Sites				
Mini-Grids & Islands				

* Includes Telecommunications, Cathodic Pipeline Protection, Navigation, and Fencing applications

2.1.2 Solar Generation Technology

Solar power generation technologies can be classed into the following categories that are described later in this section:

- Concentrated Solar Thermal
- Flat Plate Photovoltaic's
- Concentrated Photovoltaic's (an emerging technology that is a combination of Concentrated Solar Thermal and Flat Plate Photovoltaic's)

These three technologies utilise different fractions of the available solar resource. The total available solar resource, or Global Irradiance, is the sum of the two fractions of Direct Irradiance from the beam of the sun, plus the Diffuse Irradiance due to scattered non-direct beam irradiance as shown in Figure 2-1.

The two solar fractions are dependent on location, with the fraction of Direct Irradiance greatest in desert and arid regions of Australia, with Diffuse Irradiance greater in coastal regions. The Concentrated Solar Thermal and Concentrated Photovoltaic technologies can only use the Direct Irradiance fraction, while Flat Plate Photovoltaic's can use both the Direct and Diffuse fractions; thereby determining the geographical deployment of each technology.

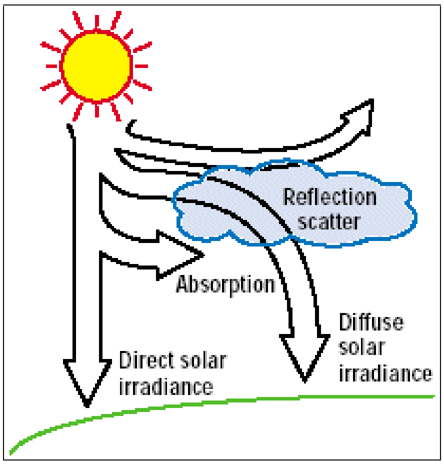


Figure 2-1: Available solar resource fractions

The other important difference between the technologies is their practical minimum and maximum deployment scales. All three technologies have *minimum* sizes determined by their major sub-components manufacturing constraints, operational efficiencies, modularity for scale up, and associated costs. Maximum sizes for all three technologies are generally dictated by budget constraints, however for off-grid scenarios this may be limited by the size of the load to be met.

2.1.2.1 Concentrated Solar Thermal Power

Concentrated Solar Thermal Power (CSP or CSTP) uses mirrors to reflect and concentrate sunlight onto receivers containing a heat transfer fluid. The heated fluid transfers the thermal energy to generate steam that then drives a steam-type turbine converting the thermal power to alternating current electricity. Table 2-2 describes the technology in more detail.

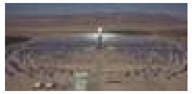
2.1.2.2 Flat Plate Photovoltaic's Power

Sunlight is received by flat plate photovoltaic (FPPV) twin layered materials that create differential charges which are converted into electricity using the photovoltaic effect. The direct current can then be directly utilised, or converted to alternating current by inverters using power electronics. Table 2-3 describes the technology in more detail.

2.1.2.3 Concentrated Photovoltaic's Power

Concentrated Photovoltaic's Power (CPV) is a technology variant on both CSTP and FPPV, whereby mirrors reflect and lens concentrate sunlight onto photovoltaic (PV) twin or multi-layered materials. This concentration effect reduces the amount of expensive photovoltaic material required per unit of power output. The differential charges between the photovoltaic materials are converted into electricity using the photovoltaic effect. The direct current is then converted to alternating current by inverters using power electronics. The concentrated sunlight also has a heating effect on the photovoltaic materials which decreases the system power output. Solutions to mitigate this heating effect are low concentration systems (2 to 20 suns) that utilise ambient air cooling, or medium (20 to 200 suns) and high (200 to 1000 suns) concentration systems requiring dedicated cooling systems for removing or utilising the surplus heat energy elsewhere. Table 2-4 describes the technology in more detail.

Table 2-2: Concentrated Solar Thermal Power Technology Description and Applications for Off-Grid Power Supply Market Sectors

Type:	Parabolic Troughs	Central Receivers & Towers	Linear Fresnel Lens	Sterling Engines
Description:	Multiple receiver arrays of parabolic trough mirrors.	Multiple heliostat mirror arrays to centralised tower receiver	Multiple receiver arrays of linear mirrors.	Multiple receiver arrays of parabolic dish mirrors.
				
Technical Maturity:	**Mature** with proven deployment & commercially available.	**Pre-commercial** under development.	**Commercial** new deployments & commercially available	**Pre-commercial** under development.
Solar Resource:	Direct Irradiance only	Direct Irradiance only	Direct Irradiance only	Direct Irradiance only
Currently deployed system size ranges:	30 MW to 350 MW (Grid Connected)	10 MW to 20 MW (Grid Connected)	10 kW to 10 MW (Grid Connected)	10 kW to greater than 25 kW in modular units for scale up
Energy Storage with:	Thermal tanks & steam plant	Thermal tanks & steam plant	Thermal tanks & steam plant	Not Known
Off-grid hybrids with:	Gas generators	Gas generators	Gas & coal generators	Not Known
Off-Grid deployment:				
Households	Not suitable	Not suitable	Not suitable	**Maybe suitable**
Pastoral Stations	Not suitable	Not suitable	Not suitable	**Potentially suitable**
Communities	Not suitable	Not suitable	Not suitable	**Potentially suitable**
Tourist Facilities	Not suitable	Not suitable	Not suitable	**Potentially suitable**
Small Industrial*	Not suitable	Not suitable	Not suitable	Not suitable
Pumping & Irrigation	Not suitable	Not suitable	Not suitable	**Potentially suitable**
Mining Grids	**Proposed**	**Potentially suitable**	**Potentially suitable**	**Potentially suitable**
Fringe of Grids	Not suitable	Not suitable	Not suitable	**Potentially suitable**
Mini - & Island Grids	**Potentially suitable**	**Potentially suitable**	**Potentially suitable**	**Potentially suitable**

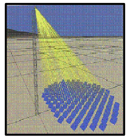
* Includes Telecommunications, Cathodic Pipeline Protection, Navigation, and Fencing application

Table 2-3: Flat Plate Photovoltaic (FPPV) Technology Description and Applications for Off-Grid Power Supply Market Sectors

Type:	**Thick Silicon**	**Thin Silicon Alloys (Thin Film)**	**CdTe (Thin Film)**	**CIGS / CIS (Thin Film)**
Description:				
	Multiple PV flat plate rigid modules of Crystalline & Polycrystalline Silicon	Multiple PV flat plate rigid modules of non-crystalline Silicon alloys or combined with Crystalline Silicon	Multiple PV flat plate rigid modules of crystalline Cadmium Telluride	Multiple PV modules of Copper Indium Gallium (Di)Selenide available in flat plate rigid *and flexible panels*
Technical Maturity:	***Mature*** & commercially available with proven deployment record.	***Mature*** & commercially available with proven deployment	***Mature*** & commercially available with proven deployment	***Pre-commercial*** and available with limited new deployment
Solar Resource:	Global Irradiance	Global Irradiance	Global Irradiance	Global Irradiance
Currently deployed system size ranges:	1 kW to 60 MW (Grid Connected)	1 kW to 5 MW (Grid Connected)	1 kW to 60 MW (Grid Connected)	1 kW to 2 MW (Grid Connected)
Energy Storage with:	Batteries	Batteries	Batteries	Batteries
Off-grid hybrids with:	Diesel & Petrol generators	Diesel & Petrol generators	Diesel & Petrol generators	Not Known
Off-Grid deployment:				
Households	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Pastoral Stations	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Communities	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Tourist Facilities	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Small Industrial*	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Pumping & Irrigation	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Mining Grids	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Fringe of Grids	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***
Mini - & Island Grids	***Suitable***	***Suitable***	***Suitable***	***Potentially suitable***

* Includes Telecommunications, Cathodic Pipeline Protection, Navigation, and Fencing application

Table 2-4: Concentrating Photovoltaic Technology Description and Applications for Off-Grid Power Supply Market Sectors

Type:	**Parabolic Troughs**	**Central Receivers & Towers**	**Flat Plate & Lens**	**Parabolic Dishes**
Description:				
	Multiple curved & parabolic trough mirrors concentrating sunlight onto PV materials.	Multiple heliostat mirrors concentrating sunlight onto PV in a central tower.	Multiple PV flat plate modules with concentrating lens for sunlight onto PV materials.	Parabolic dish mirrors for concentrating sunlight onto PV materials.
Technical Maturity:	***Pre-commercial*** under R&D development	***Pre-commercial*** under R&D development	***Commercial*** and available with limited new deployment record	***Commercial*** and available with deployment record
Solar Resource:	Direct Irradiance	Direct Irradiance	Direct Irradiance	Direct Irradiance
Currently deployed system size ranges:	Yet to be deployed	Yet to be deployed	20 kW to 10 MW (Grid Connected)	24 kW to 300 kW (Off-Grid)
Energy Storage with:	Batteries	Batteries	Batteries	Batteries
Off-grid hybrids with:	Not Known	Gas generators	Not Known	Diesel & Petrol generators
Off-Grid deployment:				
Households	***Potentially suitable***	*Not suitable*	***Potentially suitable***	***Potentially suitable***
Pastoral Stations	***Potentially suitable***	*Not suitable*	***Potentially suitable***	***Potentially suitable***
Communities	***Potentially suitable***	*Not suitable*	***Potentially suitable***	***Potentially suitable***
Tourist Facilities	***Potentially suitable***	*Not suitable*	***Potentially suitable***	***Potentially suitable***
Small Industrial*	***Potentially suitable***	*Not suitable*	*Not suitable*	*Not suitable*
Pumping & Irrigation	***Potentially suitable***	*Not suitable*	***Potentially suitable***	***Potentially suitable***
Mining Grids	***Potentially suitable***	***Potentially suitable***	***Potentially suitable***	***Potentially suitable***
Fringe of Grids	***Potentially suitable***	*Not suitable*	***Potentially suitable***	***Potentially suitable***
Mini - & Island Grids	***Potentially suitable***	***Maybe suitable***	***Potentially suitable***	***Potentially suitable***

* Includes Telecommunications, Cathodic Pipeline Protection, Navigation, and Fencing application

2.1.3 Solar Power Tracking Systems

The energy generated by solar technologies can be significantly increased using sun tracking to receive greater proportions of the incident solar energy. Sun tracking is essential for the Concentrated Solar Thermal Power and Concentrating Photovoltaic technologies, and optional for the Flat Plate Photovoltaic (FPPV) Technologies.

A variety of tracking configurations and axis of rotation can be utilised with the final choice being a balance between increased energy yield versus greater equipment purchase and maintenance costs, system complexity, and power loads for controls and trackers.

2.2 Wind Power

Wind power has been widely used for off-grid projects in Australia for numerous years, with the first record of wind turbines being installed for off-grid projects dating back to 1989 at Salmon Beach in Western Australia. To date, most off-grid projects involving wind turbines have been near the coast of Western Australia, on the Bass Strait Islands off the northern coast of Tasmania and Thursday Island off the northern tip of Queensland.

In general, the application of wind technology can be broken into 3 categories of wind turbines:

- small scale (<30 kW)
- medium scale (100 kW - 850 kW)
- large scale (>1 MW)

To date in Australia no large wind turbines have been installed for any off-grid projects with the 850 kW wind turbines installed on King Island having the largest rated output. In the majority of cases medium size wind turbines have been installed and this is largely due to the size of the load to be serviced and the benefits to off-grid projects from using multiple smaller wind turbines as opposed to a single larger wind turbine.

2.2.1 Small Scale (<30 kW)

It is likely that future off-grid projects involving wind power are going to use multiple small scale wind turbines than fewer larger wind turbines, based on the likely loads to be serviced. Already there are a number of projects that have made use of small scale wind turbines, mostly 20 kW wind turbines.

Globally, hundreds of thousands of small wind turbines have now been installed. There are a large number of manufacturers in the small wind turbine market and the selection of which manufacturer to use is likely to be driven by commercial decisions based on cost, availability, and proven performance.

To date, wind turbines manufactured by Westwind have been the most widely used in Australia (Westwind were previously based south of Perth, Western Australia but are now located in Ireland).

2.2.2 Medium Scale (100 kW - 850 kW)

As stated previously, most off-grid projects in Australia have utilised medium scale wind turbines. There are limited wind turbine models currently manufactured in this range with the major wind turbine manufacturers (Vestas, Bonus (now Siemens), Nordex etc.) that previously operated in this market no longer manufacturing wind turbines with a rated maximum output below 850 kW.

Vergnet has a range of wind turbines in the 200 kW to 1 MW range, although these are most commonly used and most relevant to remote islands in the Pacific or developing countries in Africa. Enercon has been widely used in Western Australia but sourcing Enercon wind turbines has been difficult in the Australian market for small projects. Furhlander has a 100 kW wind turbine and Nordwind has been developing a 300 kW wind turbine but neither has been installed in Australia to date. There are possibly other wind turbine models available (in particular it is likely that companies in China may be manufacturing wind turbines in this range) but these are not widely known.

2.2.2.1 2nd Hand Wind Turbines

European countries were the first to install wind power on mass. As a result, a number of these early wind farms are now undergoing upgrades to bigger and newer wind turbines (“re-powering”). Hence, large numbers of 2nd hand wind turbines are expected on the market, if they are not already available. These are likely to fall within the 100 kW to 850 kW range. The risk with these wind turbines will be assessing their remaining life, the wind conditions they have been subjected to, and whether spare parts for key components (such as blades, gearboxes etc.) remain available.

One example within Australia is the Nicholls Chicken Farm in north-west Tasmania. The Nicholls Chicken Farm installed a 2nd hand Vestas V27 225 kW wind turbine at its farm to reduce its energy bill and sell surplus energy to the Tasmanian grid. These wind turbines may be a suitable option for certain off-grid situations (and indeed new Vestas V29 wind turbines have been successfully operating on Thursday Island since their installation in 1997).

2.2.3 Large Scale (>1 MW)

As stated there have yet to be any large scale wind turbines used for off-grid projects in Australia. This is mostly due to the size of the loads to be serviced by these projects and the technical advantages of having multiple wind turbines as opposed to a single wind turbine. Otherwise there are no technical reasons why large scale wind turbines could not be utilised for off-grid projects.

All of the major wind turbine manufacturers have wind turbines available in this range, and the Chinese wind turbine manufacturers are now looking to export outside of China. China may be a cheaper source of large scale wind turbines looking into the future.

From a technical point of view, a direct drive wind turbine would be preferable for off-grid projects rather than an induction generator wind turbine, but the selection of a wind turbine in this range is likely to be made on commercial grounds like availability and cost.

2.3 Hydro Power

Although hydro power has been extensively installed within Australia, there are no known off-grid projects using hydro power. This is mostly due to the site specific conditions required for hydro power (rainfall, storage, geological conditions etc.).

From a technical point of view, hydro power is ideally suited to off-grid projects as it not only provides power (as long as there is a resource available), but the energy can be stored while the generator can provide frequency control. It is ideally suited to complement other renewable energy sources such as wind that have fluctuations in output.

2.3.1 Hydro Power Turbines

There are three main hydro power turbine types and the selection of the turbine is based on the available pressure head:

- Kaplan – suitable for low heads (2-30m), run of the river type schemes (most likely scenario for off-grid projects)
- Francis – best suited to when the pressure head is between 300m and 100m
- Pelton – suitable for when the pressure head is above 100m

2.3.2 Hydroelectric Schemes

The hydroelectric plant location enables a further categorisation by operating scheme, defined as:

- Large dams (including pumped storage)
- Run-of-river
- Reservoir based
- Canal or in a water supply pipe

2.3.2.1 Large Dams (including Pumped Storage) Schemes

Large scale hydroelectric systems require a dam, or series of dams, to store the quantities of water required by the system and minimise the impact of seasonal variations in rainfall on available generation capacity.

A small number of hydroelectric projects are also of the pumped storage type. Each station reuses the water which passes through it, by storing it in catchment areas below the station and then pumping it back up to the higher catchment dams above the station in a closed circuit arrangement. This pumping is carried out in 'off-peak' times when there is a surplus of power available from other power stations – either fossil-fuelled or other renewable energy (such as an over supply of solar or wind power.

When pumping is required, a reversal of roles occurs. The generator operates as an electric motor, receiving electricity from a nearby power station, and operates the turbine as a pump. The turbine receives energy instead of delivering it. However, in some pumped storage schemes there are two sets of equipment. One set is for generating and the other set is for pumping.

2.3.2.2 Run-of-river Schemes

Run-of-river schemes are where the turbine generates electricity when water flows down a river (some storage may be available depending on the size of the project). Generation ceases when the river dries, or the flow falls below a predetermined rate or the minimum technical flow for the turbine.

Run-of-river schemes are typically built in river valleys. Two technological options can be selected. Either the water is diverted to a power intake with a short penstock, as in the high head schemes, or the head is created by a small dam, provided with sector gates and an integrated intake, powerhouse and fish ladder.

2.3.2.3 Reservoir Based Schemes

A small hydropower scheme cannot afford a large reservoir to be constructed for the purposes of storing water to enable the plant to be operated when it is most convenient as the high cost of a relatively large dam and its hydraulic structures will be prohibitive. But if the reservoir has already been built for other purposes (such as flood control, irrigation, water abstraction for a big city, recreation area), it may be possible to generate electricity using the discharge as long as it is compatible with its fundamental use.

2.3.2.4 Canal or in a Water Supply Pipe Schemes

Hydro electricity generation can also be installed in water supply infrastructure canals, and pipes to replace existing pressure reducing and gate valves to use the pressure head that is otherwise wasted.

2.4 Geothermal Power

Geothermal power is in its infancy in Australia as a main stream source of power. The only geothermal project (grid or off-grid) that has been operating in Australia is located in Birdsville, Queensland. There are a number of pilot plants nearing completion in South Australia.

The Birdsville project has an installed capacity of 120 kW (80 kW after losses) project that draws on water from a 1,230 m deep bore in the Great Artesian Basin at a temperature of 98° Celsius (considered low temperature in geothermal power terms). The current plant is nearing the end of its design life and there are plans to increase the capacity of the plant to increase the supply of power from 25% to 100% of the town’s energy requirements.

Geothermal energy is generally sourced from one of three sources (shown in Figure 2-2):

- hydrothermal and geopressured brines (such as Birdsville)
- hot dry rock
- volcanic activity, e.g. hot springs, geysers and magma (typical of Iceland and New Zealand but not found in Australia)

2.4.1 Hydrothermal Systems

Hydrothermal systems have fluids circulating through rock pores or fractures in areas where high heat-flow is present. High-temperature hydrothermal systems are more suitable for electricity generation, while low-temperature hydrothermal systems are more suited to direct-use applications (like domestic hot water and heating).

2.4.2 Hot Dry Rock Systems

Hot dry rock systems do not have fluids naturally circulating through the rock and in most cases, the rock needs to be fractured to achieve the fluid flow required for heat transfer. Hot dry rock systems are normally associated with granites that contain anomalously high concentrations of naturally radioactive elements. The radioactive decay of these elements over millions of years generates heat, which is trapped when the granites become buried by insulating sediments.

The hot rock system is a closed-loop system that requires at least one fluid injection well and one production or recovery well. Liquid is pumped down the injection well and travels through the rock fracture network to be heated by the hot rocks. The superheated fluid then returns to the surface in the production well(s), transfers its heat to a secondary fluid or working fluid, and is then recirculated and pumped down the injection well.

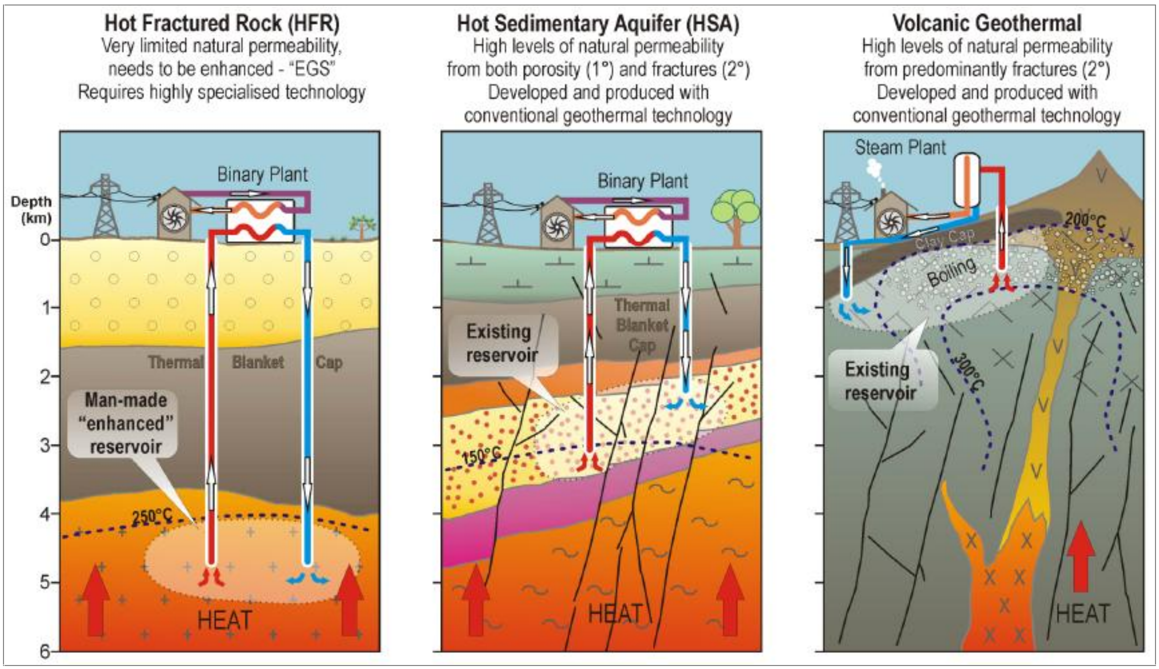


Figure 2-2: Sources of geothermal energy

2.4.3 Status of Geothermal Power in Australia and Potential for Off-Grid Use

Presently there are a number of pilot projects for geothermal power underway in Australia, predominantly in South Australia. Of these projects, due to the large cost involved in the drilling, exploration and proving the technology the scale of the projects will require them to be connected to the main grid to achieve realistic returns on the investment.

However, there are projects lined up to supply some of the larger mines in South Australia. At this point in time, it is unlikely that off-grid projects can support the use of geothermal energy in Australia based on the costs required to access the type and available resource, unless they are supplying large mining activities.

3. Available Renewable Resources

The available renewable energy resource has been mapped by the Australian Government in the Renewable Energy Atlas of Australia[2]. The solar and wind resource (presented in Figure 3-1 and Figure 3-2) has been extracted from this atlas and are included in this report to demonstrate the available resource in off-grid locations. The geothermal resource is presented in Appendix A[3].

It should be noted that the resource presented here is based on large scale modelling and is presented for comparative purposes only (not for the basis of detailed feasibility studies). The resource for any potential location should be measured and investigated appropriately.

The hydro power resource is not presented in this report as this is not publicly available and would require sophisticated modelling and data inputs to prepare.

The solar and wind resource maps have been overlaid with the approximate location of the grid network in Australia, and existing fossil fuel[4] and renewable energy power stations[5] in off-grid locations within Australia.

These are not intended to show every known fossil fuel or renewable energy power station in operation in off-grid scenarios. There are likely to be large scale mines or agricultural businesses that are using vast quantities of fossil fuel generation. In addition there are most likely a vast number of small scale renewable energy installations that are not displayed. These maps merely demonstrate that renewable energy is already in use and that there are opportunities in Australia to replace fossil fuel generation with renewable energy.

[2] http://www.environment.gov.au/renewable/atlas

[3] https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=65306

[4] http://www.ga.gov.au/fossil_fuel

[5] http://www.ga.gov.au/renewable

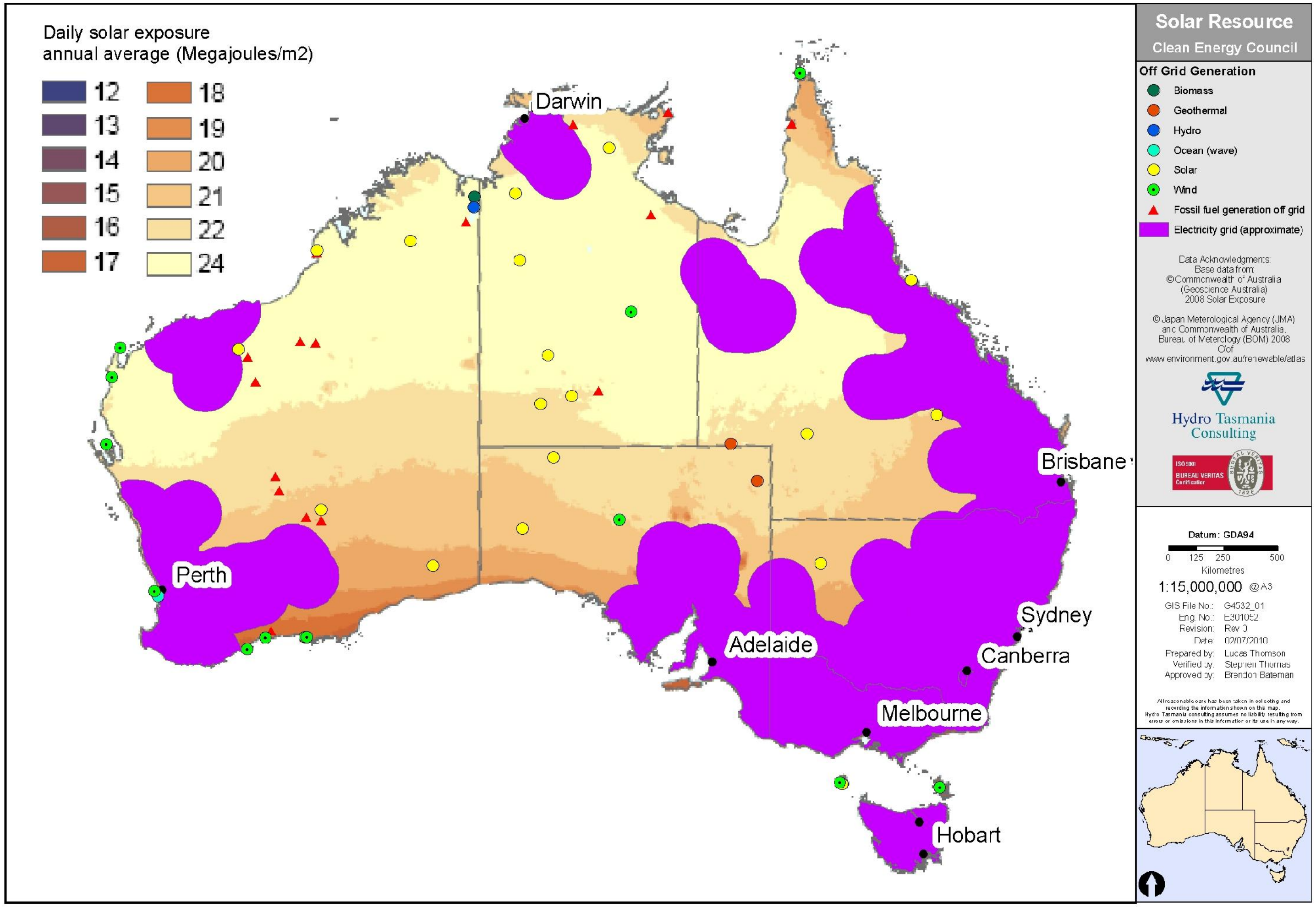


Figure 3-1: Available solar resource in Australia for off-grid projects

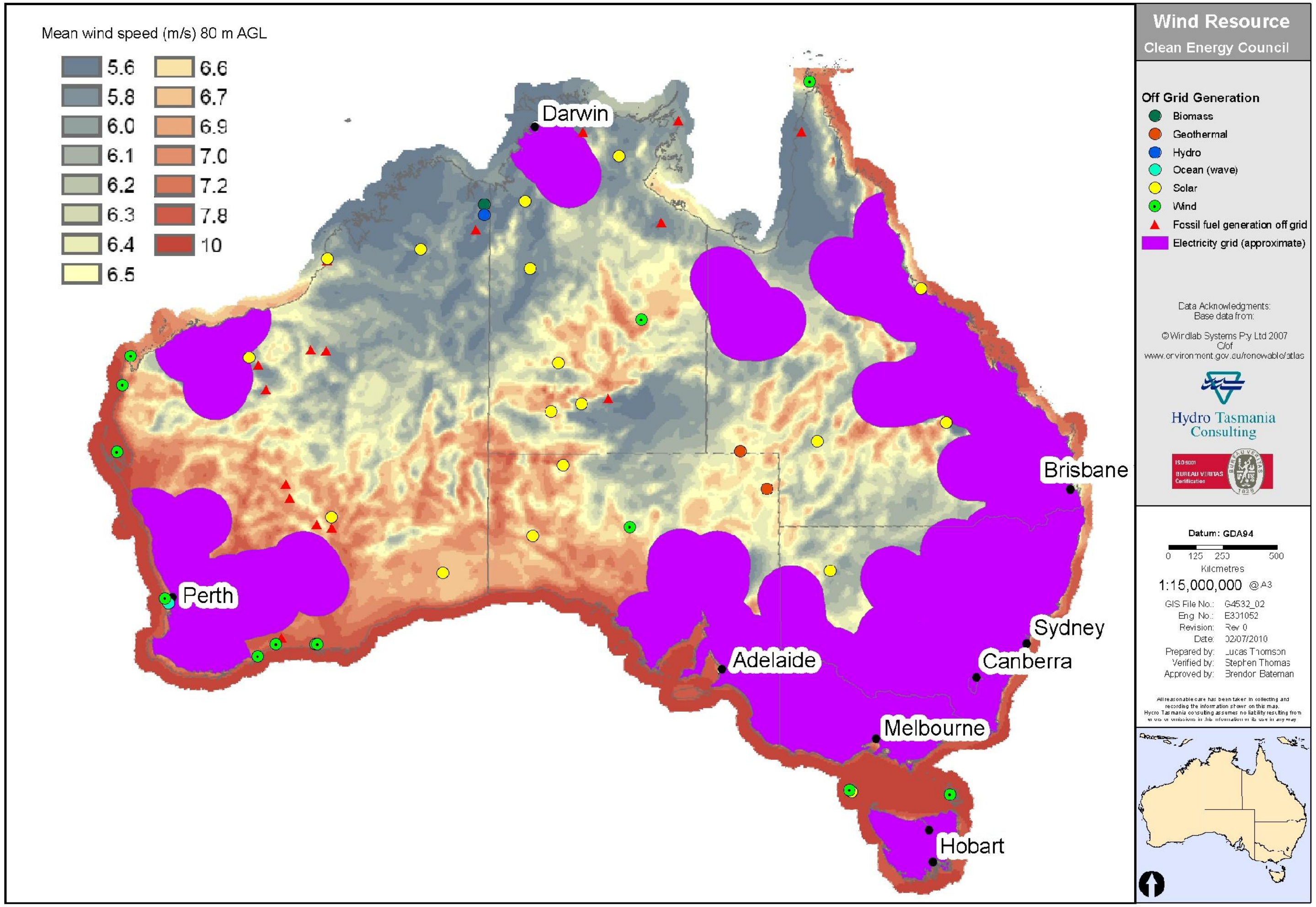


Figure 3-2: Available wind resource in Australia for off-grid projects

4. Energy Source Costs

This section discusses the typical costs of off-grid projects based on diesel production against the cost of grid connection or integrating renewable energy. The costs presented are general and are provided for comparative purposes on a broad scale and are not specific to any site.

The viability of off-grid renewable generation projects significantly depend on the maturity of the renewable technology proposed, the available resource, the project location and its remoteness, the project scale and profile of the load to be met, the alternative carbon fuel and fuel transportation costs, hybridisation and energy storage opportunities with carbon fuel generation, and the local electricity distribution location, capacity and voltage.

Only a general view of costs (presented as cost per unit of energy) is presented in this section based on publicly available documents.

4.1 Diesel Generation Costs

The major cost with diesel based generation is the cost of purchasing the diesel fuel. Figure 4-1 and Figure 4-2 display trends in the cost of diesel in Australia between 2004 and 2010 and the trends in crude oil prices between 1973 and 2009 respectively. Figure 4-2 in particular shows a dramatic increase in the price of crude oil from early in the 2000's up until 2008.

Figure 4-1 shows the price of diesel fuel peaked in Australia at around $1.80 per litre during 2008. At this time there was an increased interest in the uptake of renewable energy for off-grid power supply. However, the suppression of diesel prices that has followed as a result of the global financial crisis temporarily reduced this urgency. Predictions are that diesel fuel prices are currently at the floor and will only get higher.

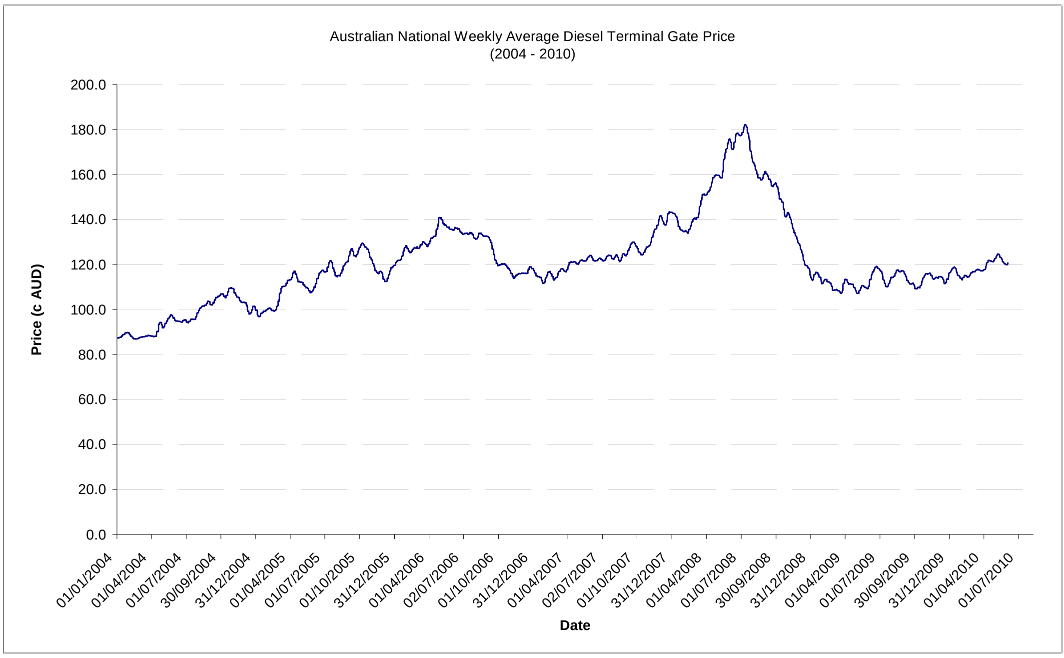


Figure 4-1: Australian National Weekly Average Terminal Gate Diesel Price (2004-2010)

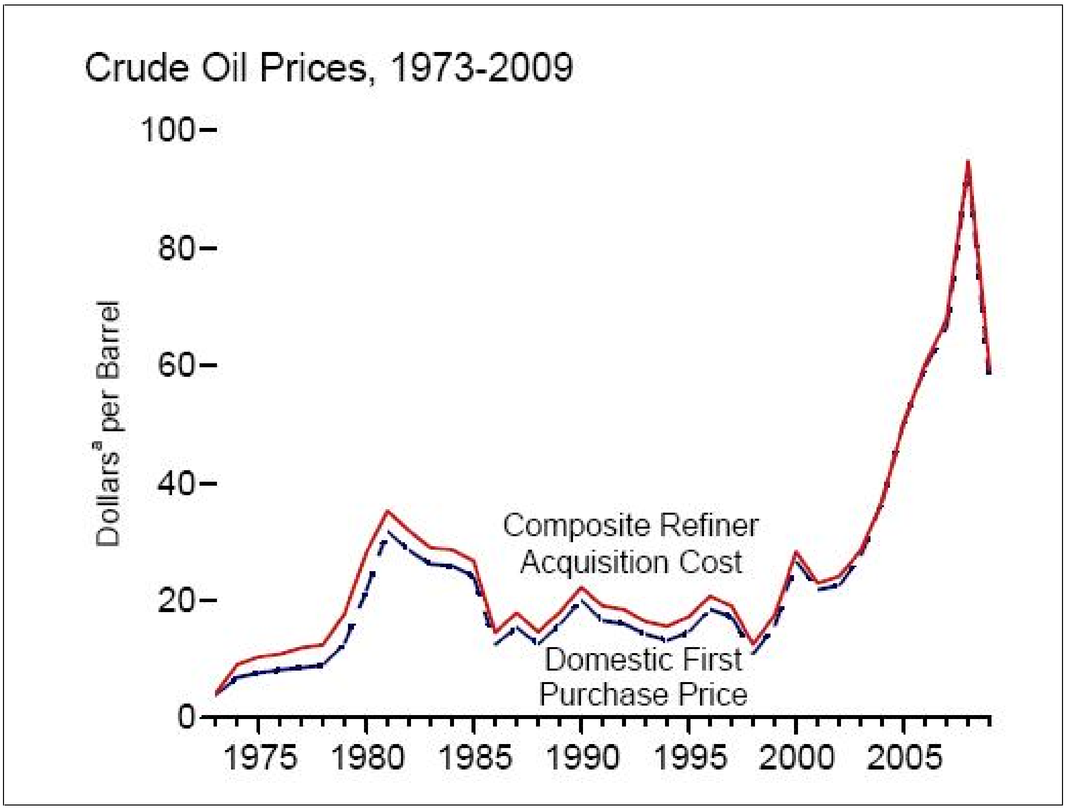


Figure 4-2: Crude Oil prices per barrel (1973-2009)

Currently the average price for diesel is around $1.40 per litre at the bowser. However, it is understood that up to 75% of diesel purchased in Australia is bought under contract and so the price is not subject to weekly variations. It is also likely that remote communities will be paying higher prices than other communities close to large population centres. Thus, the diesel prices reported here should be used as a guide only.

Information has been sought for a range of diesel generators including their cost and efficiency. Based on this data and some high level assumptions a unit cost of energy based on diesel generation has been calculated and presented in Table 4-1. The costs assume a diesel price of $1.40 per litre, increasing at a rate of 2.5% p.a. These are considered to be reasonable assumptions, and in fact, it is possible that the price will increase at a faster rate and that the price may not remain this low in the short to medium term. However, based on these calculations the range of unit cost values of $450/MWh - $500/MWh implies that renewable energy generation is likely to be competitive in many places already.

Table 4-1: Estimated Unit Cost Energy from Diesel Generation in 2010

kVA Rating	kW Rating	Efiiciency (kWh/l) (@ 75% load)	CAPEX ($)	Unit Cost Energy* ($/MWh)
500	400	3.65	850,00	$506.2
910	728	3.82	207,000	$485.2
1000	800	3.6	268,000	$514.4
1500	1200	3.83	430,000	$484.8
2000	1600	4.06	630,000	$454.2
2500	2000	3.75	780,000	$490.7

*Assumes diesel price per litre of $1.40, O&M costs of 1c/kWh and CPI of 2.5%, 20 year design life and 50% capacity factor

Other options that may be more suitable for off-grid situations, particularly those projects looking for high levels of renewable energy penetration are for low load diesel generators or those diesel generators with fly wheels in built.

There are also options to look at cheaper fuels or lower emission fuels such as:

- Ethanol
- Natural Gas; and
- Biofuels

4.2 Grid Connection Costs

The cost of connecting a new load to the grid depends on the voltage of the grid connection, the capacity required and the distance from the existing grid. Typical costs associated with a grid connection include the connection application, new transmission or distribution line and substation costs. In general, the biggest cost is the transmission or distribution line, although the substation costs can be substantial when high voltages are involved. Costs for various voltage transmission lines (both single circuit and double circuit) have been estimated and are presented in Table 4-2.

Table 4-2: Estimated high voltage transmission and distribution line costs per kilometre

	Single Circuit		Double Circuit	
Line Voltage	**Cost per km^**	**Capacity* (MVA)**	**Cost per km**	**Capacity (MVA)**
22 kV (phosphorous)	$240,000	75	$325,000	150
66 kV (phosphorous)	$365,000	75	$500,000	150
132 kV (phosphorous)	$480,000	150	$680,000	300
220 kV (sulphur)	$660,000	350	$950,000	700

^ Costs are budget price (± 30%). Environmental, access roads and land acquisition costs excluded. Costs may vary depending on the location and State.
*Capacity is based on conductor thermal limits and is not an estimate of system constraints.

In most instances the capacity required would suggest that a single circuit 22 kV line would be the preferred choice. Obviously the closer to the grid the cheaper the cost of connection and the more desirable this option becomes.

4.3 Typical Renewable Energy Costs

Estimates of the levelised unit cost of energy for different sources of grid connected renewable energy generation in 2010 were prepared by in May 2008 for the Federal Government Department of Treasury [1] and are presented in Table 4-3. The Australian Geothermal Energy Association [2] also prepared a report in February 2009 determining the levelised unit cost for a range of power generation technologies. These numbers have been included as a comparison.

Table 4-3: Estimated Unit Cost per Energy from Grid Connected Renewable Energy Generation in 2010

Generation Source	Typical Capital Expenditure ($M per MW installed)	Unit Cost Energy (Federal Government, 2008) ($/MWh)	Unit Cost Energy (AGEA, 2009) ($/MWh)
Hydro	2.0	72	n/a
Geothermal	5.0	87	99
Wind	2.4	98	102
Solar PV	7.5	333	270
Solar Thermal	5.0	200	250

It needs to be noted that the unit costs presented above need to be adjusted for off-grid projects to account for the following:

- Off-grid projects will typically have higher unit costs due to economies of scale.
- Not all renewable energy generated can necessarily be used due to load profiles. Thus unit costs per generation of renewable energy will be higher. In addition, fossil fuel generation will

be required to supplement renewable energy in times where the renewable energy is not available.

- Integration costs for off-grid projects should be lower than for grid connected projects.

Regardless, it can be seen that renewable energy generation is already close to matching the unit cost of diesel generation. The exception based on these results is solar power, but given the range of technologies available for solar energy and the decrease in prices witnessed in recent times it is likely that these unit costs are already much lower than as reported in these studies.

5. Evaluating Off-Grid Projects

This section discusses potential drivers for off-grid renewable energy projects, how projects can be evaluated and the inputs required, and discussion of contract models for developing projects.

5.1 Project Drivers

To evaluate an off-grid project looking to install renewable energy, the drivers for the investment need to be first understood. Different types of developers will have different drivers and these need to be understood before setting up models to evaluate a project.

Possible drivers for an off-grid renewable energy project:

- To provide the lowest cost of energy;
- To reduce carbon emissions;
- To trial a renewable energy technology;
- To improve the power quality and security of supply; and
- To make a return on an investment

The choice of drivers will depend on who is responsible for investing in the project, but it is important to understand the project drivers before attempting to evaluate the project. It should be noted though, that in almost all cases no project will go ahead if the project will not produce at least the same outcome as the current situation.

5.2 Project Evaluation

Evaluation of renewable energy projects is typically undertaken using discounted cash flow models. These models consider the estimated revenues and expenditures, both capital expenditure (CAPEX) and operating expenditure (OPEX), on a periodic basis for the design life of the project. The time period considered in these models is typically monthly, quarterly or annually. Considering a model run annually, in each year of the project the revenue and costs are summed and then discounted to a specified year (typically the start year of the project) using an appropriate discount rate (the discount rate reflects the cost of capital for the developer). Typically models are prepared for the existing scenario (base case) and alternative scenarios. Comparing these models demonstrates the benefits or otherwise of the alternative scenarios, often including a sensitivity analysis of key parameters.

Depending on the drivers for the project, the cash flow model can then be set up to evaluate one, many or all of the following for the project:

- Net Present Value (NPV) – This is the sum of the discounted cash flows. A positive NPV indicates a potentially attractive project. However, of more importance is the relative NPV of the alternative scenario in comparison with the existing scenario (base case). If the NPV for an alternative scenario is higher than the base case, then this scenario is potentially attractive.

- Internal Rate of Return (IRR) – This is the discount rate required to return an NPV of zero. The IRR is usually compared to a hurdle rate set by the developer for all new projects. Projects with an IRR above the hurdle rate are attractive projects.
- Return on Equity (ROE) – This is a measure of the net income derived from the project divided by the amount of equity invested in the project. A project could be funded by debt to leverage the return on equity (if capital is not available or if capital can be sourced at a rate cheaper than the internal cost of capital), assuming the return from the project exceeds the interest and financing costs.
- Simple payback time for the project – This is a calculation of the total cost over the life time of the project (the cost of CAPEX and OPEX) divided by the annual revenue of the project (expressed in terms of a number of years). The shorter the time the more attractive the project.
- Reduction in carbon emissions – The reduction in the amount of fossil fuel based generation.
- Levelised cost of energy – The unit cost of energy averaged over the life of the project based on the expected energy divided by the sum of the discounted expenditure over the life time of the project (taking into account CAPEX and OPEX).

Figure 5-1 displays a flow chart outlining inputs and how an analysis can be undertaken to evaluate potential projects. A description of the inputs typically required to undertake a discount cash flow model analysis is provided below.

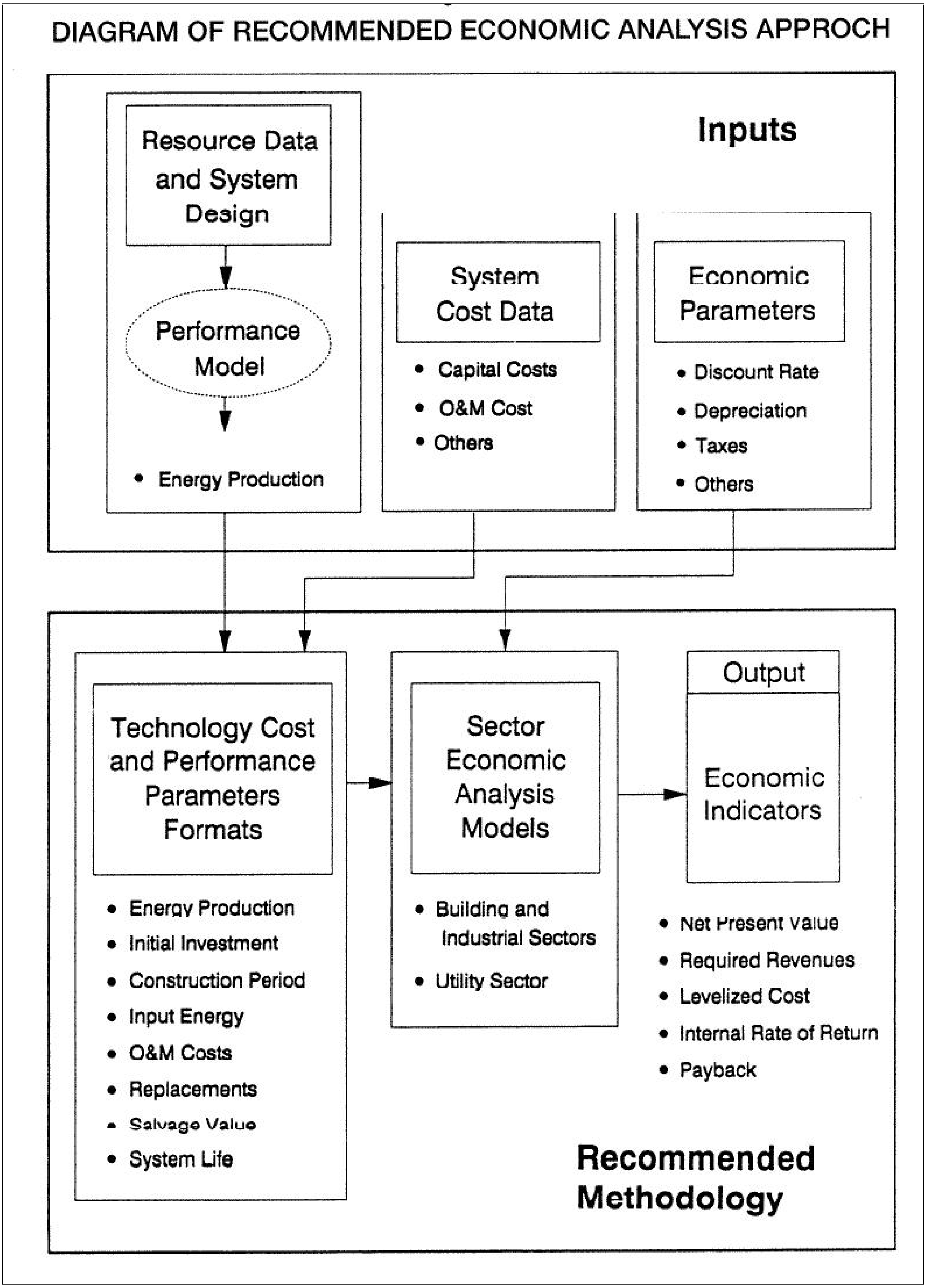


Figure 5-1: Flow chart for evaluating an off-grid renewable energy project

5.2.1 Energy Modelling

Energy modelling is required to estimate the annual energy that will be produced by the various generation sources within the off-grid project. Further modelling is then required to model the off-grid system by balancing the load with the available generation and other control system requirements to maintain adequate power quality supply.

The following data inputs are generally required for energy modelling:

- Load/demand data at a suitable time step to prepare daily, monthly and annual profiles
- Renewable energy resource data (or production)
- Renewable technology specifications
- Existing power supply specifications
- System power quality specifications

5.2.2 Estimate of Capital Expenditure (CAPEX)

This should include an estimate of all upfront CAPEX required for the project including:

- Development Costs (Feasibility studies, Environmental and Building permits, etc.)
- Power plant purchase costs (wind turbine, solar panel, hydro turbine etc.)
- Balance of plant costs (Civil and Electrical works required for installation and access)
- Any works required for connection to existing power supply or decommissioning of existing power supply
- Purchase of any spare parts
- Any planned replacement of equipment or major components before the end of the project

5.2.3 Estimate of Operating Expenditure (OPEX)

This should include an estimate of all ongoing OPEX for the project over its lifetime including:

- Fuel costs – particularly for fossil fuel based generation
- Ongoing operation and maintenance costs
- Administration costs
- Insurance
- Other annual costs (such as environmental compliance, land lease costs, rates etc.)

5.2.4 Financial Modelling Parameters

Typically these include the following depending on the sophistication of the modelling and whether tax and depreciation of assets are taken into account:

- Discount rate
- Inflation rate for operating costs and revenue streams
- Tax rate (if applicable)

- Interest rate on any loans required plus any costs associated with financing project (if applicable)
- Depreciation (if applicable)

5.3 Contract Model Options

There are a number of contract models that can be used for off-grid projects depending on the requirements of the developer. A number of models that may be appropriate for off-grid projects are described in this section. This is not an exhaustive list but details some of the more common approaches.

The choice of project delivery method is a complex issue which depends on the following:

- Developer's objectives in delivering the projects
- Existing capabilities within the Developer's organisation
- Risk appetite and tolerance of the Developer
- Financing method
- Level of scope definition required
- Schedule demands and the urgency of requirement
- Amount of innovation within the proposed project
- Legal system and sovereign risk specific to where the project is located

5.3.1 Engineering, Procurement and Construction (EPC)

This is a common form of project delivery in Australia. Under the EPC delivery method, the Developer prepares a scope of works or performance specification. Contractors then bid to undertake the design (engineering), procurement of necessary plant and materials and then construct the plant. Tenders are then called and a contract subsequently entered into by the Developer. This method is best used where there is one obvious solution, e.g. a mini-hydro plant or a wind farm that can be met by a range of equipment suppliers.

In this scenario, the Developer essentially hands over the risk to the Contractor for costs and scheduling in return for a premium on the service. The benefits to the Principal are:

- Only one contact point for the duration of the project (no micromanagement required);
- Minimal effort is required by the Principal for the project to commence;
- Construction teams can be mobilised prior to completion of detailed design to reduce the time to completion;
- Potential cost savings can be identified through collaboration between the design and construction teams; and
- The cost for the project is fixed at the start of the project so financial arrangements are known in advance and there is reduced exposure to fluctuations in the market.

The potential downsides of this arrangement to the Principal are as follows:

- The scope of works or performance specification needs to be clear and concise at the start of the project as any future changes will involve changes to the cost of the project; and
- The Contractor will be looking for ways to achieve cost saving during the project. This may affect the ultimate design life or the long-term performance of the assets over time if adequate supervision, checks or performance guarantees are not in place.

A variation of this contract is to engage the Contractor to operate the asset for a period of time after completion to reduce the risk to the Developer of the asset not meeting the desired level of performance.

5.3.2 Construct to Design (CTD)

This is another common form of project delivery in Australia. As with EPC the Developer prepares a conceptual design for either the whole of the works or various packages of works. Tenders are then called and contract(s) subsequently entered into by the Developer.

The advantage of this method of delivery is that it allows both the design and construction to be contested with the result that the Developer receives transparency in pricing for the design and construction packages. Whether the Developer receives a project best reflecting their requirements depends on the quality of the brief put out firstly to the Designer and then the quality of the documents developed on behalf of the Developer by the Designer.

The CTD method needs to be used carefully in order not to constrain industry input from equipment suppliers and installers. It is best used where:

- The Client does not have a clear idea of the type of installation they want; and
- There is no one obvious way to meet the Client’s need rather there is a range of potential solutions.

In this instance it is important to ensure that the optimal solution is identified. The CTD approach can be used with a range of financing options, but will always mean that the bulk of the risk associated with resource availability, land tenure, planning etc. remain with the Developer. As with other methods there is a risk of variations and potential for legal and project related claims during the construction if the design or scope of works is not comprehensive.

5.3.3 Build Own Operate (BOO)/Build Own Operate Transfer (BOOT)

These contracts are of greatest relevance where a Public Authority requires private investment to finance rapid development, or a commercial organisation wishes to focus its financial resources on its core business and have the design, construction and operation of a project outsourced. It is particularly suited to green field projects. Payment to the Contractor (“Operator”) is not a lump sum paid up front, but periodic payments spread over a relatively long period of time (although usually shorter than the design life of the project).

5.3.4 Alliance

A Project Alliance can be defined as an arrangement where the Developer and one or more service providers (Designer, Constructor, Supplier, etc) work as an integrated team to deliver a specific project under a contractual framework where their commercial interests are aligned with actual project outcomes (i.e. payment is aligned performance).

An alliance is a form of “relationship contracting”, where the emphasis is placed on collaboration to achieve a shared goal, rather than “hard contracting” where each party puts its own interests above the project’s interests.

Project Alliances are most frequently used where the scope of works and project risk cannot be well defined at tender stage. Alliancing is most often used in the public sector where it has been used to avoid some of the poor project outcomes achieved using traditional hard dollar contracting methods, or in the mining, resource and oil and gas sectors where the focus is to get high quality outcomes as quickly as possible.

Alliancing caps the risk of the “Non-Client Participants” to a pre-defined percentage covering profit and overheads, and thus places the bulk of financial risk of major project problems with the Developer.

This style of contract results in a project where the Developer, Designer, Constructor and Supplier work together to arrive at a completed works that seeks to meet the objectives of all participants. The different commercial arrangements (win-win or lose-lose) within Alliancing frees the parties from having to concentrate on downside risk, and allows projects teams to focus on best for project outcomes.

A concern from the Developer’s perspective may be that the alliance is not formed competitively and so the process does not result in demonstrably competitive pricing. Instead Alliancing focuses on the principle that a high level of cooperation between Developer, Designer, Contractor and Supplier will allow more innovation and result in a better solution and consequently a lower price. Within the above methods there is a wide variation in the way alliances are implemented.

6. Integration of Renewable Energy into Hybrid Systems

This section discusses the integration of renewable energy with fossil fuel based hybrid systems and methods and technologies that can improve the integration such as energy storage and other enabling technologies.

6.1 Integration of Renewable Energy

In general, the following connection aspects need to be considered for renewable energy technologies to best meet load requirements:

- Scheduled and unscheduled generation
- Base Load, Peaking Capability and Spinning Reserve
- Location of the generation source to the load centres

6.1.1 Scheduled and Unscheduled Generation

6.1.1.1 Hydro Power

Most hydro power comes in the form of hydroelectric power where the potential energy of stored water is used to drive a water turbine and generator. In this case the energy extracted from the water depends on the volume and on the difference in height between the source and the water's outflow (head). The amount of potential energy in water is proportional to the head.

Because hydro energy can be stored the generation can be scheduled – based on knowledge of the available energy in storage.

6.1.1.2 Geothermal

Geothermal power can be stored or set to a constant value (i.e. not variable) and hence the generation can be scheduled in advance if the amount of available energy is known.

6.1.1.3 Wind

As the wind is variable in nature and cannot be stored, it cannot be scheduled. To maximise its effectiveness in fossil fuel displacement the power system needs to be able to take full advantage of any wind generation that is available at any given time, otherwise the energy will be wasted.

This variable nature in wind generation, particularly at lower wind speeds where the power output fluctuates, can cause some operational issues particularly in determining the number of fossil fuel generators to run as spinning reserve to cater for any large scale wind generation fluctuations.

In practice this becomes a risk trade off based on maximising fuel efficiency and minimising run hours on the fossil fuel generating sets and system security in the event of a large enough drop in wind generation with insufficient spare capacity to cover the generation deficit.

In a typical large scale wind hybrid system the number of fossil fuel generators running will be determined by the net deficit of system load not supplied by the wind with a maximum allowable wind penetration[6] level. In the event of too much wind generation in the system, the wind generation is limited by;

- Switching off wind turbines in the case of simple wind turbines;
- Limiting the output in the case of more advanced wind turbines (feathering blades); or
- Diverting excess energy into resistor banks or energy storage.

The amount of fossil fuel spinning reserve run becomes dependent on how much spare capacity is required to either meet a reasonable drop in the wind or maintain critical supplies, and a confidence factor is also often applied depending on the variability (e.g. 10 minute standard deviation).

Resistor banks can be a simple solution if there is significantly more wind than load demand as they can be switched in a number of small steps to match the variability in the wind and minimise spinning reserve. At lower levels of excess wind energy, spinning reserve needs to be increased to mitigate drops in the wind which create a generation deficit.

Energy storage technologies enable the excess energy to be stored and released at times of short and medium term deficit and aid system stability as well as offsetting fossil fuel use.

6.1.1.4 Solar

Solar is similar to wind in that the energy must be used whenever it is available, however with a predictable and stable climate reasonable predictions of the available output can be made several days in advance. A large solar array's output will reduce slowly in the case of cloud cover and thus there is increased ability to run less fossil fuel spinning reserve.

6.1.2 Base Load and Peaking Capability

Geothermal generators typically have significant thermal inertia – they are well suited to constant load but are not well suited to fast variations in load. Similarly, to make best use of wind and solar all of the generation should be used when it is available.

The net result is that any variation in the renewable energy supply and system load in a fossil fuel based system will be seen by the fossil fuel generators.

Compared with the size of the individual load variation seen by a base load generator on an existing fossil fuel system as a result of a load change (there is a larger number of fossil fuel units individually thereby seeing a lower load variation), a base load generator on a renewable energy system will see a larger load variation as a result of a load change (as there is a smaller number of fossil fuel units).

[6] Maximum percentage of system load supplied by wind generation at any given time.

Similarly in the case of wind generation where the output is variable, the fossil fuel units will be exposed to the summing effects of system load changes and wind generation changes.

The combined effects of this impact on the fossil fuel generators should be assessed to determine the likely swings, the maximum allowable generation from renewable sources and any spinning reserve requirements.

6.1.3 Location and Connection of Generation Options

When integrating renewable energy into existing off-grid power supplies, in an ideal world the renewable energy sources would be located at the source of existing generation. This minimises changes required in the power system as power generated always flows in the same direction and control of the generation elements can be simpler. If this is not possible, connections close to large load centres are preferable as the variability in renewable generation is less likely to cause unacceptable variation in the system voltage (as well as reducing distribution losses in the system as the energy is generated where it will be used).

6.1.3.1 Operation, Control & Technology Advances

The complexity of the controls required to operate a diesel based system will depend on the level of unscheduled renewable energy being put into the system and the desired diesel reduction. As a rule of thumb as the level of unscheduled renewable energy (i.e. wind) required increases in larger systems (>100 kW), the level of complexity in control increases to mitigate the risk associated with a deficit of energy and the impact this has on diesel operation.

In recent years the power electronics used with many energy storage technologies allows them to act as a scheduled generator which is capable of maintaining the system voltage and frequency while also absorbing excess energy in the system. These technology advances effectively mean that if suitably sized, power systems can be run without the need for diesel generators which were previously required to set and maintain system voltage and frequency as well as providing spinning reserve.

Currently in the renewable energy industry these advances in power electronics along with increases in diesel fuel prices have created off the shelf inverter/chargers systems with are capable of controlling a small power system up to approximately 150 kW. Beyond this mark special systems are currently still required although with further increases in fuel price, larger units based on the concept of the smaller units are likely to appear on the market in the next few years as the basic development concept is well proven, and the systems are becoming expandable and can be up-scaled.

6.2 Energy Storage

While not a source of renewable energy in their own right, energy storage systems could play a large role as enabling technology for variable renewable energy resources such as wind and solar, by storing excess energy at times of high energy production and releasing at times of low production. Energy storage in combination with renewable energy sources can effectively create a more reliable base load supply. This allows the amount of fossil fuel generation to be reduced, and potentially fossil fuel generators to be turned off.

6.2.1 Issues for Energy Storage Systems

While individual storage technologies have particular limitations and benefits in targeted applications, all have two major weaknesses, particularly when considered in conjunction with renewable energy installations:

- The high capital cost of the storage system that includes the "charging" sub-system, the storage sub-system and the "discharging" sub-system that must interface to the AC electrical grid.
- The round-trip efficiency of a storage system is always less than 100%.

6.2.1.1 Resistor Banks v Energy Storage

In cases where the cost of renewable energy such as wind is relatively low in comparison to the energy storage technologies, simple and cheap enabling technologies such as resistor banks which use excess energy generated to heat air or water rather than attempt to store the energy may be more viable. This is particularly true where the investment in energy storage systems is better placed in additional renewable energy generation (i.e. extra wind turbines). Thus importance of good accurate financial and technical modelling of any proposed system becomes an important part of any decision basis.

6.2.2 Energy Storage Technologies

Electricity is not usually stored per se. Energy storage technologies instead convert electricity to other energy forms, with a characteristic turnaround efficiency usually driven by the simplicity or complexity of conversion and reconversion between electricity and the stored energy form.

- It can be 90-95% efficient to convert electricity to kinetic energy and back again by speeding up or slowing down a spinning flywheel.
- Batteries (electrochemical energy storage devices) can be relatively efficient (~70-80%) if charged and discharged at moderate rates.
- Storing electricity by compressing and later re-expanding air is usually less efficient (~75%), since rapid compression heats up a gas, increasing its pressure and thus making further compression difficult.
- Hydrogen storage of electricity has relatively low round-trip energy efficiency (~30-50%) from the combination of electrolyser efficiency and re-conversion technology back to electricity. Internal combustion motor-generator sub-systems are not as efficient as fuel cells, although the latter are not yet commercially available at cost-effective prices per kilowatt.
- Converting electricity to high temperature heat, storing that heat and then reconverting it to electricity has a similarly low round-trip efficiency (~30-40%) (Pearl Street, May 2004).

- It must be noted that capital cost and round-trip efficiency can be "traded-off", at least to some extent. For example, a storage technology with low capital cost but low round-trip efficiency may well be competitive with a high cost, high round-trip efficiency technology.

It is the total energy cost of the integrated system (renewable electricity plus storage) that matters from a project point-of-view.

6.2.3 Electrochemical Energy Storage

The oldest and most established way of storing electricity is in the form of chemical energy in batteries. A battery comprises of one or more electrochemical cells and each cell consists of a liquid, paste, or solid electrolyte together with a positive electrode and a negative electrode. During discharge, electrochemical reactions occur at the two electrodes generating a flow of electrons through an external circuit. The reactions are reversible, allowing the battery to be recharged by applying an external voltage across the electrodes.

Battery systems range from mature and reliable technologies, such as lead acid, which have been proven and developed over many years, to various newer designs which are at different stages of development, including sodium sulphur and sodium nickel chloride. In recent years, new developments have been driven by the demands of consumer electronics, portable and transport applications, although there is increasing interest in the use of large scale batteries for utility energy storage applications.

Electrochemical approaches that are either in use and/or potentially suitable for utility scale battery energy storage applications include lead acid, nickel cadmium, sodium sulphur, sodium nickel chloride and lithium ion.

Electrochemical flow cell systems, also known as redox flow cells, convert electrical energy into chemical potential energy by means of a reversible electrochemical reaction between two liquid electrolyte solutions. In contrast with conventional batteries, redox flow cells store energy in the electrolyte solutions. Therefore, the power and energy ratings are independent, with the storage capacity determined by the quantity of electrolyte used and the power rating determined by the active area of the cell stack.

6.2.4 Pumped Hydro Storage

Refer to the description in Section 2.3.2.1.

6.2.5 Compressed Air Energy Storage (CAES)

In a CAES plant, compressed air is used to drive the compressor of the gas turbine, which makes up 50-60% of the total energy consumed by the gas turbine system. The most important part of the CAES plant is the storage facility for compressed air. Usually a man-made rock cavern, salt cavern, or porous rock, either created by water bearing aquifers or as a result of oil and gas extraction, can be used. Aquifers in particular can be very attractive as storage media because the compressed air will displace water, setting up a constant pressure storage system. The pressure in the alternative systems will vary when adding or releasing air. There have only been a few CAES installations worldwide.

As with hydro pumped storage capacity, the development of CAES is limited by the availability of suitable sites. As a result, current research is focused on the development of systems with man-made storage tanks, so-called “small CAES”.

6.2.6 Kinetic Energy Storage (Flywheels)

Flywheels are kinetic energy storage devices, and store energy in a rotating mass (rotor), with the amount of stored energy (capacity) dependent on the mass and form (inertia), and rotational speed of the rotor. An accelerating torque causes a flywheel to speed up and store energy, while a decelerating torque causes a flywheel to slow down and regenerate energy.

The main feature of flywheel energy storage (FES) systems generally is that they can be charged and discharged at high rates for many cycles. Typical state-of-the-art composite rotor designs have specific energy of up to 100 Wh/kg, with high specific power. The state-of-charge is easily assessed as a function of angular velocity, which is readily measured. The main drawbacks of flywheels are cost, and the relatively high standing losses.

Flywheel energy storage technologies broadly fall into two classes; low speed flywheels, which are commercially available; and high-speed flywheels, which are just becoming commercial. Low speed flywheels, with typical operating speeds up to 6000 rev/min, have steel rotors and conventional bearings.

High-speed flywheels, with operating speeds up to 50,000 rev/min using advanced composite materials for the rotor, have been under intensive development to increase the energy storage density and reduce unit cost. Composite materials are suitable for flywheel rotors due to their light weight and high strength. Lightness in high speed rotors is good from two points of view, as the ultra-low friction bearing assemblies are less costly, and the inertial loading which causes stress in the material at high rotational speeds is minimised. High strength is needed to achieve maximum rotational speed. Therefore, advanced composite rotors enable the storage of greater amounts of energy on a specific weight basis, in comparison with other materials. A further important consideration is that fibre reinforced composite rotors fail in a less destructive manner than metallic rotors, and are thus intrinsically safer.

Currently the main stationary applications are in uninterruptible power supplies (UPS), power quality (PQ) systems, and trackside support in traction (rail) systems. Several manufacturers have foreseen possibilities of applications in peak shaving in electrical power systems, and for power smoothing in renewable energy systems, however very few units have been installed in this application.

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7. Case Studies

Case studies for 3 off-grid renewable energy projects are presented in Appendix B. The projects presented are:

- Coral Bay – a wind-diesel hybrid system
- Cape Barren Island – a wind-solar-diesel hybrid system
- Windorah Solar Farm – a solar-diesel hybrid system

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8. Potential Federal Government Actions

This section discusses potential actions or support that the Federal Government could implement that would improve the uptake of off-grid renewable energy. An obvious solution would be direct funding of renewable energy projects but this could be seen as intervention in the market and is probably not a wise policy decision. Instead, actions have been identified that would assist or encourage investment in the market by developers and/or utilities.

8.1 Decrease the Uncertainty in Energy Modelling

A big reason why many off-grid renewable energy projects have difficulty proceeding is due to the lack of data available either in the load to be met, the available renewable energy resource or both. The lack of information increases the uncertainty in the projects and can lead to difficulties for projects seeking external funding sources. To decrease this uncertainty, funding or assistance could be provided to undertake the following activities:

- Provide metering to collect load/demand data for existing and potential off-grid power supplies.
- Provide strategically located long-term resource data collection for renewable resources – in particular wind and solar. These may have wider benefits for the renewable energy sector and not just for off-grid applications. The task would involve the installation and upkeep of:
    - Wind monitoring masts
    - Solar ground stations

The locations would need to be decided based on industry consultation to maximise the benefits.

8.2 Certainty on price triggers

There are three areas of revenue/cost for off-grid projects that are directly influenced by Government policy and introduce uncertainty to the evaluation of these projects. They are:

- The application of the price of diesel fuel through the diesel excise;
- The price of Renewable Energy Certificates (RECs); and
- The future price of carbon emissions

Providing stability and certainty with regards to these three measures allows developers to plan and evaluate with increased certainty and will assist in the uptake of renewable energy off-grid projects.

8.3 Taxation Incentives for Off-Grid Renewable Energy Projects

To assist with the viability of off-grid renewable energy projects, off-grid projects using renewable energy could be provided with special (lower) tax rates or deprecation rates that would improve the viability of renewable energy over fossil fuel based generation. No recommendation is made on what these rates should be or if they should be assessed on a project by project basis.

8.4 Loans for Renewable Energy Projects

Rather than direct funding of projects, the Government could provide low cost loans to fund capital expenditure (CAPEX) or operational expenditure (OPEX) for renewable energy projects directly replacing fossil fuel generation for off-grid projects. This would assist projects by lowering the rate of return required for a project to be feasible and hence increase the viability of more projects.

9. Conclusion

Renewable energy as a source of power for off-grid projects is ready for implementation now. There are already numerous projects within Australia where renewable energy has been integrated into off-grid power supplies successfully.

Presently solar power or wind power are the chosen forms of power supply based on their ability to be installed virtually anywhere. In particular, based on the available resource solar power appears to be the preferred choice for northern parts of Australia and wind power for coastal regions in southern parts of Australia. However, the preferred power source should be based on an assessment of the best outcome of the project based on the projects drivers.

Other mainstream renewable energy power supply options of hydro power and geothermal power have been rarely used in off-grid scenarios in Australia due to the absence of site specific conditions that they require. Thus it is unlikely that they will be suitable for future projects, although they should not be precluded from preliminary assessments. Other forms of renewable energy supply (such as wave or tidal power) are still in their infancy and are also site dependant and thus unlikely to be suitable in the near future.

Some of the key drivers that will affect the uptake of renewable energy for off-grid projects include:

- The existing price of generation for the particular off-grid project – in particular the price of diesel fuel (or other fossil fuel);
- The available renewable energy resource;
- The availability of funding to finance the installation of renewable energy; and
- Federal Government policy decisions in the areas of:
    - the price of carbon emissions in the future;
    - certainty around Renewable Energy Credits; and
    - tax and depreciation.

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10. References

[1] ACIL Tasman, *Projected energy prices in selected world regions,* May 2008

[2] Maclennan Magasanik Associates, *Comparative Costs of Electricity Generation Technologies*, February 2009

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Appendices

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A Geothermal Resource in Australia

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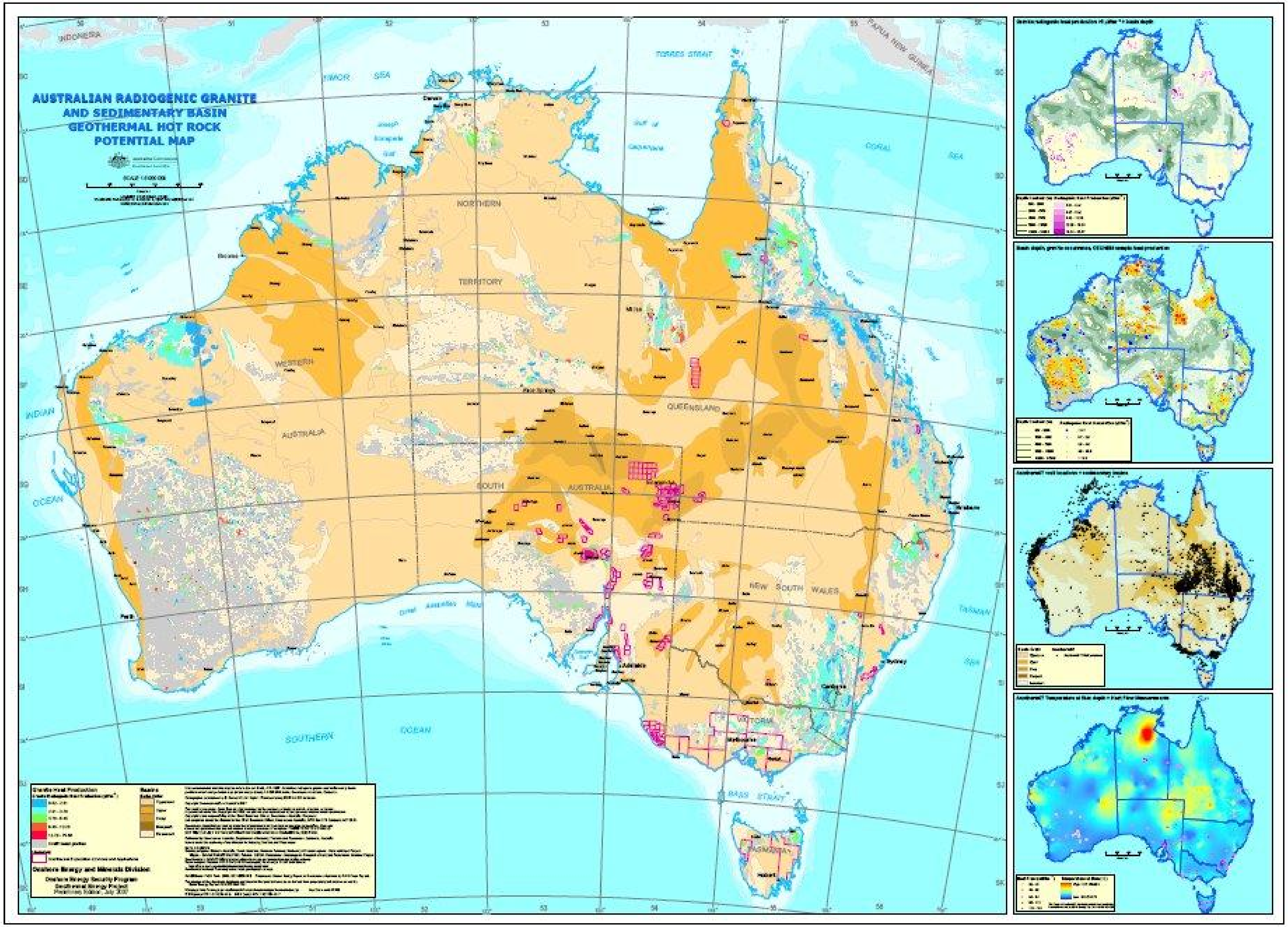
AUSTRALIAN RADIOGENIC GRANITE
AND SEDIMENTARY BASIN
GEOTHERMAL HOT ROCK
POTENTIAL MAP
INDONESIA
TIMOR SEA
TORRES STRAIT
PAPUA NEW GUINEA
CORAL SEA
NORTHERN
TERRITORY
WESTERN
AUSTRALIA
QUEENSLAND
SOUTH
AUSTRALIA
NEW SOUTH WALES
INDIAN
OCEAN
SOUTHERN
OCEAN
TASMAN
SEA
BASS STRAIT
TASMANIA
Sydney
Canberra
Melbourne
Hobart
Brisbane
Adelaide
Perth
Darwin
Granite Heat Production
Basins
Onshore Energy and Minerals Division
Onshore Energy Security Program
Geothermal Energy Project
Preliminary Edition, July 2007

B Case Studies of Off-Grid Renewable Energy Projects

B.1 Coral Bay Wind-Diesel System

Verve Energy, Horizon Power and Powercorp successfully installed a wind farm at Coral Bay in August 2007 comprising of three 275kW Vergnet wind turbines (rated to 200 kW), seven 320 kW low-load diesel engines and one of Powercorp's proprietary technology 500kVA Powerstore units (a flywheel and low load diesel generator).

The wind turbines can be lowered if a cyclone threatens the town and are capable of producing up to 45% of the community's electricity requirements. The wind turbines are light-weight, two-bladed downwind machines. They are induction type wind turbines where power output varies with frequency. As the wind instantly changes, the machines experience incredibly fast power responses. The PowerStore unit provides system stability.

Successful integration of the diesel generators, the PowerStore and the wind turbines relies on a series of complex control algorithms to ensure correct sharing between the devices to meet the demand of the variable consumer load. In periods of high wind, the PowerStore is charged. In periods of low wind, the energy stored in the PowerStore is injected back into the power system.

Since commissioning, Coral Bay power station has consistently achieved instantaneous wind penetrations of 90%. This means that at any one time, up to 90% of the power delivered to the consumers is coming from the wind. This significantly reduces the environmental effects from the power station through reduced diesel fuel consumption and fewer greenhouse gas emissions.

Coral Bay electricity consumers are now entitled to a uniform tariff and are eligible for rebates.

More information on this project can be found at:

http://www.verveenergy.com.au/mainContent/sustainableEnergy/OurPortfolio/Coral_Bay_Wind_%26_Diesel_System.html

or

http://www.pcorp.com.au/index.php?option=com_content&task=view&id=110&Itemid=164

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B.2 Cape Barren Island

Case study

Wind, solar and diesel power system Cape Barren Island

Services provided

- Evaluation of demand requirements
- Design of renewable energy solution
- Liaison with local community and assessment of needs and consequent demand
- Energy efficiency opportunity assessments
- Training of local community members in power station maintenance

Project background

The previous power generation system on Cape Barren Island was unreliable and the client needed to replace the system with a renewable, cost efficient and reliable energy source.

Project description

Entura evaluated the demand of the community, and energy efficiency opportunities, and then designed and built a renewable energy solution incorporating wind turbines, solar PV panels and diesel backup.

Environmental surveys were conducted for noise, flora, fauna and heritage issues, and planning applications were submitted to local authorities. The design was also subject to economic analysis with cost benefit and present value analysis completed.

How we added value

Entura's project staff worked with the client to ensure that government renewable energy rebates were realised.

Project construction stage

The training of community members to perform basic maintenance duties was incorporated into the construction and commissioning phases. The training was designed to Australian qualification framework standards and provides a pathway to advanced electrical qualifications.

Key results

The final design incorporated 40 kW of power via two Westwind turbines on 15 metre towers, and 3 kW of backup solar. Low maintenance battery banks store excess wind energy for times of variable wind speed, and this is supplied to the 11 kV distribution system to meet demand.

Two 65 kW diesel generators back up the system and are invoked at times of low battery voltage levels. The system is controlled by an Ingecon inverter.

Client
Department of Families, Community Service and Indigenous Affairs

Project location
Tasmania, Australia

Date of project
2008

Type of project
Remote area power system

Purpose of project
Renewable energy supply to Cape Barren Island

B.3 Windorah Solar Farm